Delivering the CT2S computational workflow directly to the clinic

Griffiths W. [1,2], Furnass W. [1,4], Tooley M.P. [1,4], Marzo A[1,2], Li X.[1,2], Bhattacharya P.[1,2], Allsopp J.[5] , Viceconti M.[1,2,6], Wood S.[1,5], Narracott A.J.[1,3]

[1] The Insigneo Institute for *in silico* Medicine, University of Sheffield, UK

[2] Department of Mechanical Engineering, University of Sheffield, UK

[3] Department of Infection, Immunity & Cardiovascular Disease, University of Sheffield, UK

[4] Department of Computer Science, University of Sheffield, UK

[5] Scientific Computing Group, Sheffield Teaching Hospitals Foundation Trust, Sheffield, UK

[6] Department of Industrial Engineering, Alma Mater Studiorum - University of Bologna

1. Introduction

In recent years there have been significant developments in the application of computational workflows to enhance the clinical decision-making process. Many of these applications have been led by groups with an engineering focus and direct delivery of workflows within the clinical environment remains relatively uncommon. Due to the complex nature of patient specific anatomy and physiology, central to the effective development of state-of-the-art computational tools, workflows often require High Performance Computing (HPC) approaches and infrastructure to produce accurate, clinically relevant, output parameters. To improve clinical uptake of such technologies there is a need to provide direct access to such workflows to clinical end-users without exposing the complexity of the underlying HPC environment. This abstract describes the development of a software framework to deliver an existing HPC computational workflow Computed Tomography to Strength (CT2S), which provides quantitative metrics of bone strength based on CT images, directly to the clinical end-user. This provides the opportunity to initiate the request for computational analysis directly from the clinic, and returning an analysis report directly to the requesting clinician.

2. Method

Computed Tomography to Strength (CT2S) provides an estimate of the strength of an individual-specific femur under a series of loading conditions using finite element models generated from computed tomography (CT) scans. This is achieved through the creation of a finite element model of the femur with personal-specific mechanical properties estimated from CT scans. The femur model is then used to simulate various loading conditions representing a range of falling scenarios. CT2S has been shown to provide better accuracy in predicting strength than DXA-aBMD, especially in clinical studies with femoral strength as the endpoint [Viceconti et al (2018)].

The engineering elements of the workflow consist of the following steps:

- Semi-automated segmentation of bone anatomy from input DICOM images
- Meshing of 3D anatomy from segmented surface to define the finite element domain
- Specification of local material properties for the finite element mesh based on bone density measures derived from CT image intensity
- Solution of the finite element model under a set of loading conditions

- Analysis of strain distribution to estimate bone strength

The finite element analysis is undertaken using ANSYS Mechanical software with typical mesh sizes of the order of 300,000 elements, resulting in analysis times of around 90 minutes per load case for contact mechanics model and 8 minutes for the Multiple Point Constraint model using the ShARC Tier 3 HPC hosted at the University of Sheffield (2016 processors and 8832 GB RAM).

In order to deliver this engineering workflow to clinical end-users an additional software framework has been developed to wrap the HPC engineering elements of the workflow and automate data entry and results reporting from the perspective of the clinical end-users. This software framework consists of the following elements, several of which are common to other computational workflows developed as part of the EPSRC MultiSim project (http://multisim-insigneo.org/):

- CT2SWebApp: provides the CT2S web site (https://ct2s.insigneo.org/ct2s/) as shown in figure 1. The web site is the mechanism for clinical users to initiate a request to perform a CT2S analysis and provides functionality to enter the structured data fields required to inform the finite element analysis (age, BMI, etc.)
- django-multisim: provides common web app functionality to multiple web services and includes DICOM file submission using Google Drive / XNAT APIs.
- AMQPClient: provides common RabbitMQ messaging functionality to multiple MultiSim apps.
- DataExchange: provides Google / XNAT file transfer functionality to multiple MultiSim apps.
- DICOMAnonymiser: a standalone DICOM anonymisation service.

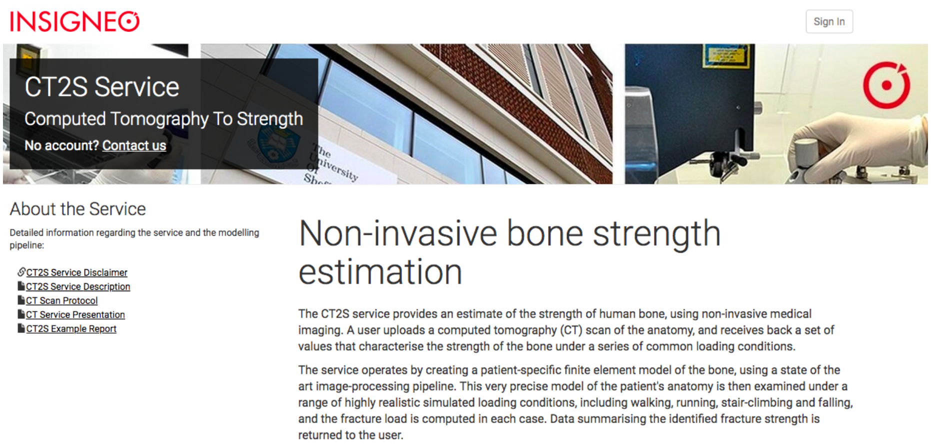

Figure 1 *CT2S web site – mechanism to allow request for HPC analysis directly by clinical end-users*

The operation of the workflow is illustrated schematically in figure 2.

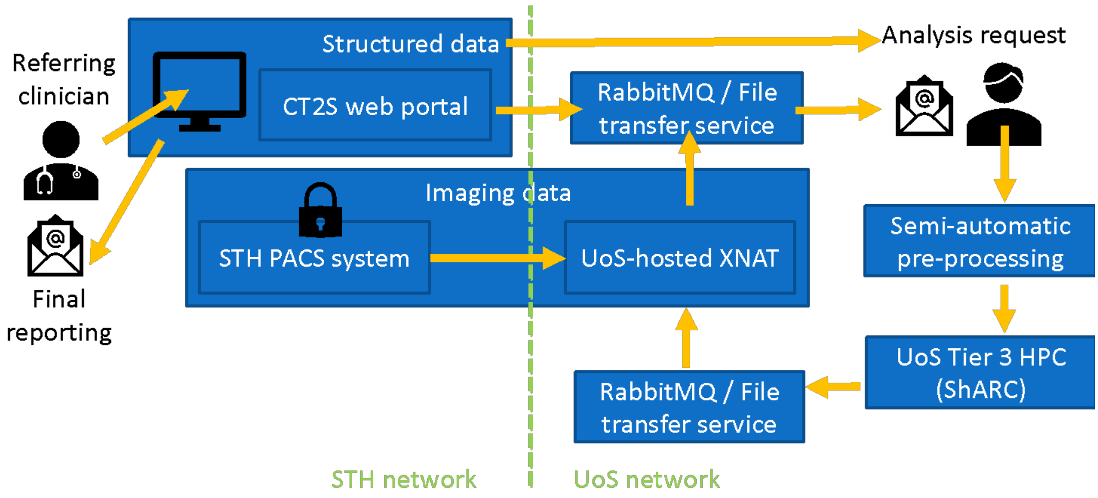

***Figure 2** Operation of CT2S workflow from initial clinician request to final reporting of bone strength assessment*

In addition to data entry within the CT2S web portal the clinical team are required to request transfer of the patient DICOM images from the Sheffield Teaching Hospitals (STH) NHS Foundation Trust PACS system to a University of Sheffield hosted XNAT database. This transfer process is facilitated by the Scientific Computing team at STH and incorporates their own in-house anonymisation step (separate from DICOMAnonymiser) to remove all personal data from the DICOM images. Consequently, all information identifying the patient remains within the STH network, and the referring clinician assigns an independent, anonymous, patient ID within the CT2S web portal when the analysis is requested and this ID is used to identify the associated imaging data within the XNAT database.

The django-multisim, AMQPClient, DICOMAnonymiser and DataExchange services are used to orchestrate processes within the University of Sheffield network which includes an automated request for analysis to a designated email account. DICOMAnonymiser (which contains STH-supplied code) provides an additional anonymisation step because django-multisim based web services aren't guaranteed to be fed data from within STH. Due to the semi-automated nature of the image segmentation, some manual intervention is required during pre-processing stages, subsequent mesh generation, load definition and finite element solutions are automated using software-specific scripting mechanisms.

Simulation outputs are uploaded by a workflow operator to the corresponding job ID's web page using a HTML form. Once all the required fields have been supplied, an option to download a pdf report in a standardised format appears on the job's page. At this point, the requesting clinician is automatically sent an email with a link to this page. Email notifications are also sent whenever the job is updated (automatically or not) midway through.

3. Results and conclusion

The software elements described above have been deployed to provide an automated approach to data transfer between the University of Sheffield and STH networks. This allows the CT2S computational workflow to be initiated from within the clinical environment, return workflow outputs directly to the requesting clinician. Future work will include assessment of the ease-of-use of the web portal by clinical end-users and further refinement of the simulation processes to reduce the level of manual intervention required by research staff supporting operation of the CT2S service.

4. Acknowledgements

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5. References

Viceconti, M., et al. (2018) 'Are CT-Based Finite Element Model Predictions of Femoral Bone Strengthening Clinically Useful?', Curr Osteoporos Rep., 16(3), pp. 216-223. doi: 10.1007/s11914-018-0438-8.